Designing of Biocompatible Antennas for Body Centric Communication

A Research Synopsis

Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Engineering

By

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1. AREA OF RESEARCH

Biocompatible antennas are a recent area of research that can facilitate remote communication with medical implants in Body Centric Communication.

2. INTRODUCTION

In the last decade, we have seen significant improvements in our understanding of the communications process between wireless devices co-located on the human body. Body-Centric Wireless Communications is a new area of research with the use of wearable and implantable wireless devices connected through body-area networks.

A body area network consists of in-body and on-body (wearable) nodes that continuously monitor the patients' vital information for diagnostic and therapeutic purposes.

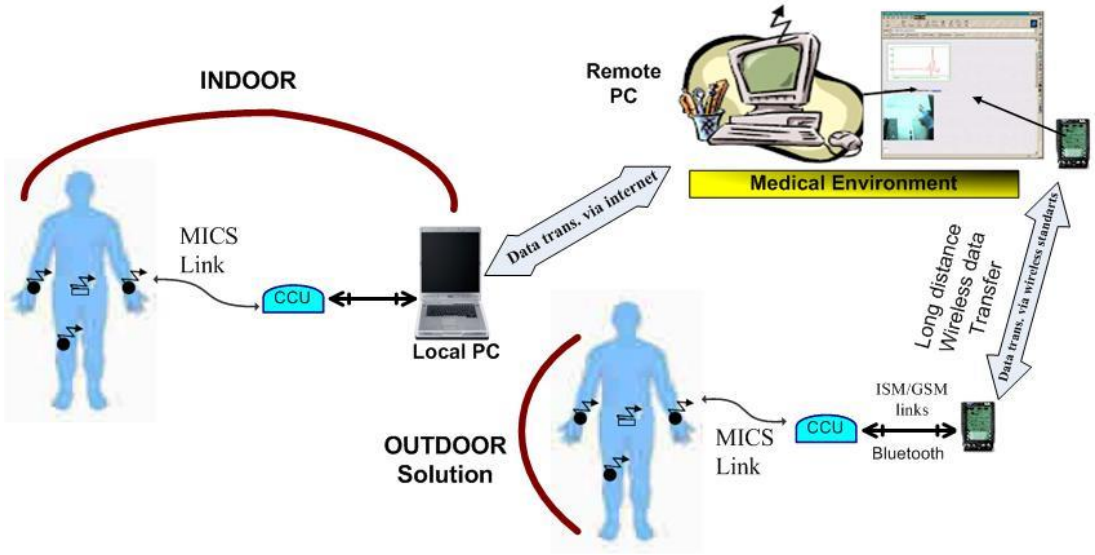

Fig. 1: Generic healthcare system working in a Wireless Body Area Network (WBAN) [1].

While the technology is still in its primitive stage it is being widely researched and once adopted, is expected to be a breakthrough invention in healthcare, leading to concepts like telemedicine and mHealth becoming real.

The main goal of a healthcare monitoring system with a wireless implantable device is to provide reliable information from inside of the human body to an external Base Station (BS). A wireless implantable system for data telemetry comprises several salient aspects as illustrated in Fig. 2.

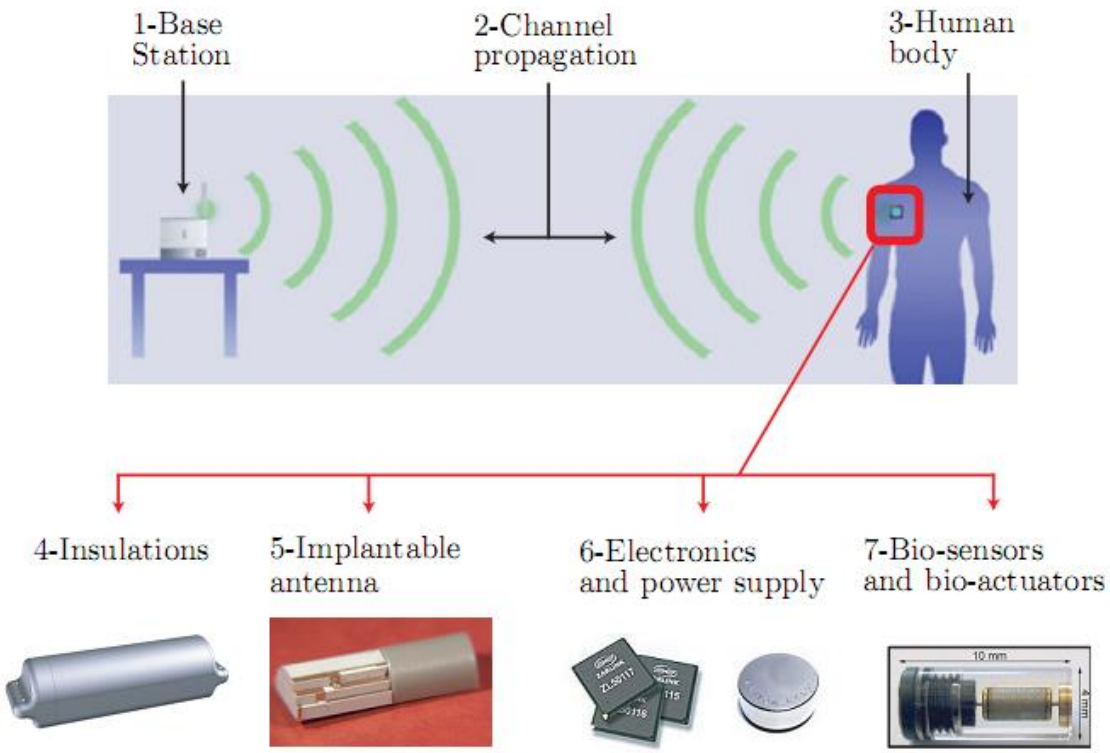

Fig. 2: Salient aspects in a wireless BAN system for data telemetry [2].

1) Base Station: A general Base Station provides interface between body nodes (transceiver) to external environment. It comprises of several sub-systems, for instance:
    - a control module to drive the entire system and to store the measurements.
    - a receiver module including antennas, etc.
2) Channel Propagation: The analysis of the EM propagation from the implanted (on-body) nodes to the Base Station is another important aspect.
3) Human Body: The human body is of primary relevance for an implantable device. Its complex, dispersive and highly lossy characteristics unavoidably affect the analysis, design, realization and characterization of implantable antennas, thus the wireless performances of the entire system.
4) Insulations: The presence of a biocompatible insulation is mandatory for any implantable (wearable) device so as to avoid any adverse reaction of the living tissues. In fact, insulating layers either placed around the antenna or on the surface of the human skin, enhance the EM transmission from an implantable radiator to the Base Station.
5) Implantable Antennas: The design of a specific radiator is the key aspect of an implantable device working in a WBAN of a few meters range. Characteristics such as radiation efficiency, bandwidth, return loss, the coupling with the lossy biological tissues and the use of the available volume are essential for the data communication.
6) Electronics and Power supply: This unit supports the processing capabilities and delineates the working power requirements.

7) Bio-sensors and Bio-actuators: They are basically transducers that sense physiological signals from the human body and deliver electrical quantity to antenna.

This area relies on the feasibility of medical implanted device inside the human body that is comfortable and that do not impair normal activities of patient.

The implanted (or wearable) antenna is the key aspect of the system. This proposal deals with the design of biocompatible microstrip patch antenna that can be used easily integrated in or over the body.

Biocompatibility is related to the behavior of biomaterials in various contexts. The term refers to the ability of a material to perform with an appropriate host response in a specific situation [3]. The ambiguity of the term reflects the ongoing development of insights into how biomaterials interact with the human body and eventually how those interactions determine the clinical success of a medical device (such as pacemaker, hip replacement or stent).

As per D. Williams, biocompatibility refers to the ability of a biomaterial to perform its desired function with respect to a medical therapy, without eliciting any undesirable local or systemic effects in the recipient or beneficiary of that therapy, but generating the most appropriate beneficial cellular or tissue response in that specific situation, and optimizing the clinically relevant performance of that therapy [4].

According to the International dictionary of medicine and biology [3], biocompatibility is the capability of a prosthesis implanted in the body to exist in harmony with tissue without causing deleterious changes.

3. LITERATURE REVIEW

The literature survey has been categorized in following sections based on different aspects reported:

3.1 Technologies being used

There are different technologies possible for wireless communication with an implanted device. Until recently, there is no dedicated technology that is being used for implantable (or on-body) devices.

The WBAN uses licensed Wireless Medical Telemetry Services (WMTS), licensed Medical Implant Communication Services (MICS), unlicensed Industrial, Scientific, and Medical (ISM) band, Ultra-wideband (UWB) etc. for biotelemetry [5].

Wireless Medical Telemetry Service (WMTS) is a wireless service specifically defined in the United States by the Federal Communications Commission (FCC) for transmission of data related to a patient's health (biotelemetry) in 2000. The bands defined are 608-614 MHz, 1395-1400 MHz and 1427-1432 MHz. Devices using these bands are typically proprietary i.e. authorized users such as physicians and trained technicians are eligible to use this band. Further, the use of these bands has not been internationally agreed to, so many times devices cannot be marketed or used freely in countries other than the United States [15].

The state-of-the-art in the research field of implanted devices has shown that MICS (402-405 MHz) band can be utilized in communication with medical implants [6]. The European Telecommunications Standards Institute (ETSI) and Federal Communications Commission (FCC) have standardized the MICS. The maximum emission bandwidth to be occupied is 300 kHz. The Equivalent Radiated Power (ERP), i.e. the maximum field-strength in any direction should be equal to, or lower than, what a resonant dipole would give in its maximum direction at the same distance, with the dipole being fed with a signal of 25 μW (Wiki, 2013).

The ISM bands (2.4-2.4835 GHz) are defined by the International Telecommunication Union (ITU) or the use of radio frequency (RF) energy for industrial, scientific and medical purposes other than communications.

The Ultra-wideband (UWB) radio is an emerging technology in the field of biomedical communication. Federal Communications Commission (FCC) regulates that the frequency for the UWB technique is from 3.1 to 10.6 GHz. UWB allows high-speed data telemetry over short distances.

3.2 Design constraints and Requirements:

The Design constraints and Requirements for Implantable Antenna are as follows:

a) Biocompatibility of Antenna

In-body antenna must be biocompatible in order to avoid direct contact between body implanted device and human body tissue, because there is possibility of shortening due to conductive nature of human body tissue. The most widely used technique is to cover the metallic radiator with a superstrate layer of biocompatible material having high dielectric constant [7]. Commonly used biocompatible materials are silicon (permittivity $\varepsilon_r = 3.1$, loss tangent $\tan\delta = 0.0025$), Macor ($\varepsilon_r = 6.1,\ \tan\delta = 0.005$), teflon ($\varepsilon_r = 2.1,\ \tan\delta = 0.001$), ceramic alumina ($\varepsilon_r = 9.4,\ \tan\delta = 0.006$) etc. [8].

In [6], Scarpello et al. have demonstrated an implantable slot dipole conformal flexible antenna embedding in biocompatible material Polydimethylsiloxane (PDMS) operating in ISM Band. The

dielectric properties of the PDMS were characterized at 2.45 GHz, to be $\varepsilon_r = 2.2$ and $\tan\delta = 0.013$.

b) Antenna Size

The body implanted devices or antenna must be miniaturized in size. Recent advances in fabrication technology have led to ultra-small design for implantable medical devices. For example, if a half dipole antenna is designed at 403 MHz (λ=744 mm), the physical length of antenna should be $L = \frac{\lambda}{2} = 372\,mm$ in free space. However, it should be noted that when the antenna is implanted inside the human body tissue, the effect of body is taken into account. In [6], it is reported that the electrical length is reduced by almost seven times as in free space, when it is implanted inside human body. Still, the antenna is bigger in size to implant. So, various methods have been illustrated in the literature to downscale the size of antenna further.

i. Lengthening of current flow path by using Planar Inverted F-Antenna (PIFA), meandered, spiral, waffle-type, and hook-slotted shaped structure as shown in fig. 3 [9].

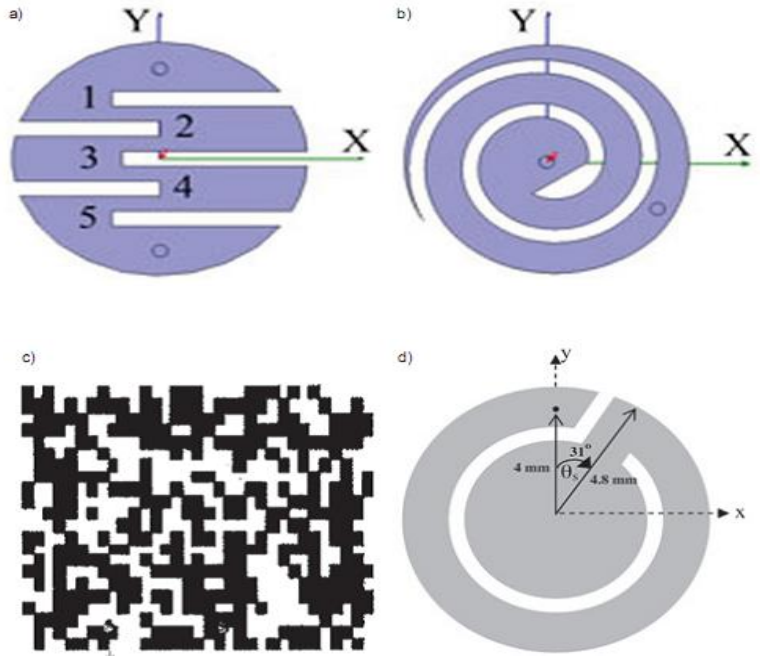

Fig. 3: Lengthening of the current-flow path (a) meandered, (b) spiral, (c) waffle-type, and (d) hook-slotted shaped patches [9].

ii. The length of current flow path can be increased almost *n*-times by vertically stacking *n* number of patches. In [10], Huang et al. demonstrated a triple band implantable antenna that covers MICS band at 402 MHz and ISM band at 433 MHz and 2.45 GHz using a π-shaped radiator with a stacked and spiral structure as shown in fig. 4.

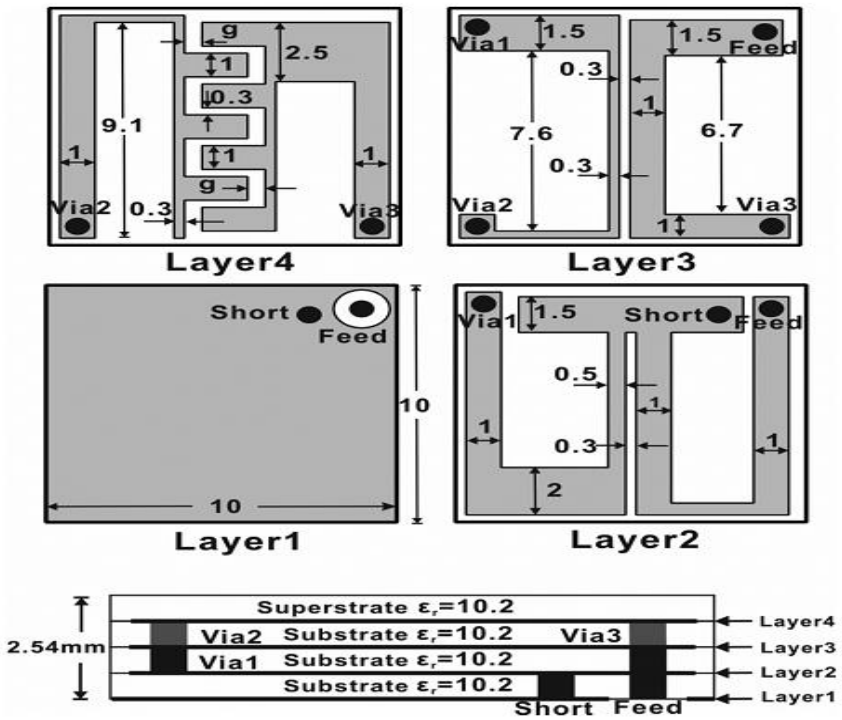

Fig. 4: The geometry of the triple-band implantable antenna [10].

iii. By using high permittivity biocompatible superstrate, one can reduce the effective wavelength of implantable patch antenna [11].

c) Patient Safety Regulations

The allowable power incident on the implanted antenna is limited, keeping an eye on patient's safety. The peak spatial-average Specific Absorption Rate (SAR) prescribed by IEEE C95.1-1999 [12] over any 1-g of tissue is 1.6 W/Kg. ICNIRP [13] limits the SAR averaged over 10-g of tissue to 2 W/Kg. Implantable antennas having low electric-field intensities are preferable to make sure the absorbed power by human body tissue is limited.

d) Low Power Consumption

Low power consumption is desirable to minimize heating problem and control SAR.

e) Far-field Gain

WBAN comprises of implanted nodes that may send the signal to exterior base station placed at some distance from body (typically, 2-3 m in Indoor). Since, the far-field gain is solicited [9], but there is restriction due to limit of SAR and the effective radiated power (ERP). The miniaturized shape of antenna also degrades the electromagnetic performance.

3.3 Human body Tissue modeling for Numerical Simulation and Analysis:

Since human body tissues are inhomogeneous, dispersive and lossy ($\varepsilon_r \neq 0, \sigma \neq 0$) in nature, One has to take care of the effect of human body while designing implanted (or wearable) antennas.

In order to test the implantable system, the implantable device is numerically simulated in artificially modeled human body environment and it is called as body phantoms or simply phantoms.

A large number of models to predict the effects of the human body on the characteristics of implanted antennas are available in the literature. For ease and simplicity, canonical models are often being used. These may be single layer (e.g. Fig. 5(a) [14]) or multilayer (e.g. Fig. 5(b) [14], e.g. Fig. 6 [6]).

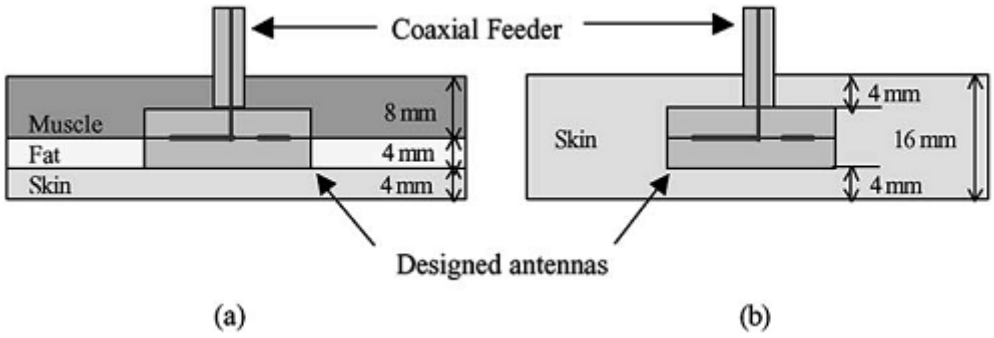

Fig. 5: Simplified planar geometries for the design of low-profile antennas implanted in the human chest (a) Three-layer geometry (b) Single-layer geometry [14].

In [14], the spiral microstrip antenna and a planar inverted-F antenna design at 402–405 MHz have been simulated at 402–405 MHz by using body phantom as shown in Fig. 5.

In [6], an implantable flexible slot dipole, operating in the Industrial, Scientific, and Medical (ISM) band; has been simulated in canonical model as shown in Fig. 6.

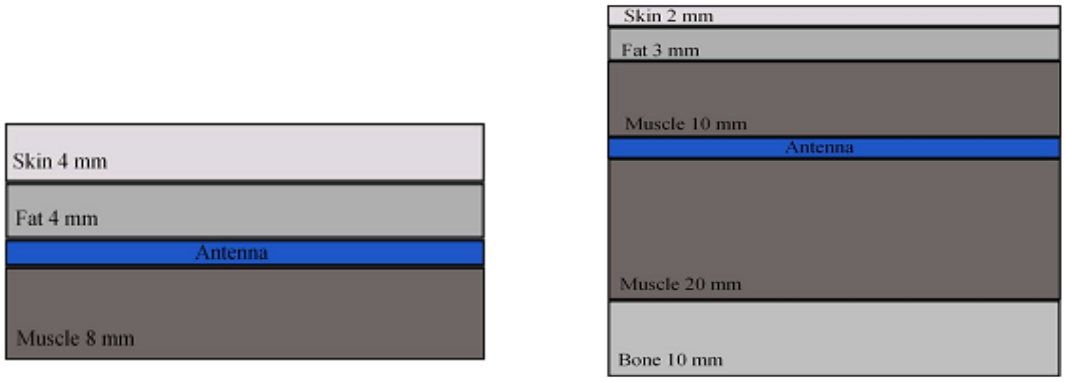

Fig. 6: (a) Three layers (b) five layer geometry for the design of the slot dipole antenna [6].

To obtain more realistic result, anatomical tissue model are used. These models are developed by Computer Tomography and Magnetic resonance imaging techniques. Anatomical models have been reported in [11], [14].

4. OBJECTIVE OF THE STUDY

Of late there have been growing interests of wireless communication in biomedical fields. The most of the works deal with implantable and biocompatible antennas, but many of these antennas are limited by low efficiency, low bandwidth, considerable power generation, less biocompatibility, degraded signals at far field and comparatively bigger size.

So, our challenge is to design such antennas which have improved characteristics.

5. TOOLS AVAILABLE FOR NUMERICAL SIMULATION:

The various electromagnetic (EM) solvers are available and also reported in literature for implantable antenna design. These EM simulators based on the finite-element (FE) method (e.g. Ansoft HFSS) [8, 9], and Finite-difference Time-domain (FDTD) method (e.g. CST Microwave Studio [4], SEMCAD) [7].

- HFSS or CST Microwave Studio will be used as simulator.

6. EXPERIMENTAL INVESTIGATION:

After complete satisfying simulation, considering all condition and requirements, the antenna prototype can be prepared and experimentally investigated in liquid phantom or animals' tissue.

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